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222

THE INSULATING VALUE OF COMMERCIAL DOUBLE-WALLED BEEHIVES

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CONTENTS.

	Page.
Description of the hives and conditions under which tests were made	1
Insulation of the hives tested	2
Tests	3
Comparative value of various insulating materials	5
Tests in the apiary	7
Conclusions	8

There are several beehives with double walls on the market which are widely used, and there has been considerable discussion among beekeepers as to their comparative value. During the summer of 1915 certain tests were made of the insulating value of all such hives on the American market, and at that time some of the data obtained in the experiments were sent to the manufacturers of these hives to aid them in any efforts they might make to construct hives suitable for winter use, but the data have not previously been published. The purpose of these tests was to discover what, if any, defects exist in these hives, what type of construction and insulation gives the best results, and especially to determine whether these hives have adequate insulating value for wintering bees in the North. It should be emphasized that these are tests of insulating value, and as such the problem of the type of entrance was not included, in all cases the entrances being closed during the tests. This is part of the work on wintering bees on which Mr. George S. Demuth and the author were engaged for several years, and Mr. Demuth assisted in the work here reported. The results should be interpreted in conjunction with previous publications of the Department of Agriculture on wintering of bees.

DESCRIPTION OF THE HIVES AND CONDITIONS UNDER WHICH TESTS WERE MADE.

Since colonies of bees vary in strength, and consequently in their temperature requirements and heat production, it would obviously be unsafe to use such a variable heating unit in making comparative tests of the insulating value of the hives. An ordinary 16-candle-power carbon filament electric lamp was used as a heating unit, the same lamp being used in all the tests. Fluctuations in voltage were

ironed out by using the lamp continuously for several days in each hive.

All hives used were new and unpainted.

All hives used were constructed of pine, usually white pine. There is, of course, variation in the insulating value of various woods, but it is believed that in the hives tested the greater insulating value lies in the materials used directly for insulation.

All hives had a capacity of 10 Langstroth frames.

All joints which would in the apiary be stopped with propolis were sealed with beeswax to prevent loss of heat by convection currents through cracks. In the tests of Hives F2 and H, the temperatures of the insides of the hives were sufficiently high to melt the beeswax, but this had little if any effect on the results, as the cracks were still closed by the liquid wax.

All covers were of wood covered with metal, except as noted.

All bottoms were of $\frac{7}{8}$-inch wood, except as noted.

When sawdust was used for insulation material it was thoroughly mixed and poured in, not tightly packed. Trays, when used, were filled level full and stroked off. When any material other than sawdust was used for insulation, this is so specified.

All hives during the tests rested on two horizontal tiles kept in the same location, so that all hives had the same opportunity for loss of heat through the bottoms during the tests.

The tests were made in a well-insulated room in the cellar of the laboratory, in which the variation in room temperature was never over 1° C. in 24 hours. In this way undue fluctuations in outer temperature were avoided. The temperature varied only about 5° C. (see column 1 of accompanying table) during the entire series of experiments, extending over several weeks in the summer, in spite of the fact that the electric lamp gave off heat practically all of this time.

All temperatures were taken by means of thermo-couple thermometers, readings being taken from the room above, thus avoiding sudden changes in the temperature of the air about the hives.

INSULATION OF THE HIVES TESTED.

The following descriptions show the amount of insulation used in the several hives and indicate the type of construction. Where the same hive was used in different ways, the variations are indicated and the experiments are designated by numbers following the hive letter, as E1, E2.

Hive A.—Two walls of $\frac{3}{8}$-inch wood. An air space (empty) is provided on sides and ends $\frac{3}{4}$ inch in width, lined with paper. The top is covered by a tray extending to the inner hive wall only and filled with sawdust to the cover.

Hive B.—Two walls of $\frac{3}{8}$-inch wood, the insulating space on sides and ends being 2 inches, filled with sawdust. Tray filled with sawdust on top, extending to the outer hive wall.

Hive C.—Two walls of $\frac{13}{16}$-inch to $\frac{7}{8}$-inch wood, insulating space 1 inch, filled with sawdust. Tray filled with sawdust extends to inner wall of hive only.

Hive D.—Same as Hive C, except for cover construction. A larger tray is used, extending to the outer hive wall. In D1, no tray was used, but sawdust was placed in the collar at the top of the hive. In D2, the tray was used, but an all-wood cover was used in place of one of wood covered with sheet metal. In D3, the sawdust in the sides and ends was replaced by a special insulating material used in refrigerator construction, made of flax board. In D4 no insulating material was used in the sides and ends of the hive, this being left as an air space.

Hive E.—A single-walled hive of $\frac{3}{4}$-inch material made large enough to allow room for a lining of $\frac{1}{2}$-inch insulating material, much like that used in Hive D3. In E1 no insulation was provided below but two thicknesses were placed on top; in E2 a $\frac{1}{2}$-inch layer of the insulating material was placed above the bottom, as would not be practicable in apiary use, and only one layer was placed on top.

Hive F.—An ordinary single-walled hive with $\frac{7}{8}$-inch sides and ends and a $\frac{3}{8}$-inch wooden cover, but with a covering made of $1\frac{1}{2}$-inch commercial insulating material of flax board. In F1 there was no insulation on the bottom, whereas in F2 the same thickness of insulating material was placed on the bottom as on top and sides, the regular hive bottom being removed. In all cases the insulating material was wired together to prevent the passage of convection currents through the corners.

Hive G.—A single-walled hive of $\frac{7}{8}$-inch wood, used as a check. A "telescope" outer cover and thin inner cover were used.

Hive H.—Same as Hive B, except that a double bottom, not included in the hive as sold, was built to provide for 2 inches of sawdust insulation below.

TESTS.

Data were obtained concerning the thermal conductivity of each hive as a whole. In each case the electric lamp was inserted, all cracks closed, the entrances stopped with cotton, and the current turned on. Readings of temperature of the air within the hive were made until the inner temperature remained constant with relation to the outside temperature (room temperature). This required several days for each hive, and by this means the full capacity of each hive for retaining the heat given off by the lamp was measured. The results of these tests are shown in Table I, column 13, which gives the

temperature of the air inside the hive 2 inches from the cover with relation to the room temperature. In interpreting the figures in this column it should be remembered that the higher the temperature reached the better is the insulating value of the hive as a whole. There is, as would be expected, a higher temperature near the cover than near or on the bottom, due to convection currents (columns 12 and 13).

To determine any defects in construction with regard to insulating value, pairs of thermo-couple thermometers were fastened on the bottom, one side, and top of each hive as tested, the thermometers being fastened closely to the hive so as to obtain the temperature of the hive material rather than that of the surrounding air. The thermometers of each pair were directly opposite each other, thus indicating the relative amount of heat which was passing through the hive at that particular point. In this way the comparative insulating values of the top, sides, and bottom were obtained. It will be seen from the table that in all cases more heat escaped through the hive bottom than through the top or sides. In interpreting the figures in columns 5, 8, and 11, it must be borne in mind that the greater difference in temperature between the outside and inside of the hive at the place tested, the less the heat that is being lost at that point. However, care must be exercised in interpreting these figures, for the higher the temperature within the hive, the greater the difference between outside and inside temperatures becomes, and consequently there is more tendency for heat to escape.

DISCUSSION.

Air space vs. packing.—To determine whether the space between the walls of a double-walled hive should be left empty or should be filled with insulating material, Hive D was used in two tests. In test D4 the space was left unfilled, while in D1 it was filled with sawdust packing, both hives being provided with the same top insulation, and both having no insulation at the bottom other than the wood. With air space the inner temperature was 34.8° C. above the room temperature, while with sawdust packing it was 39.9° C., a difference of 5.1° C. in favor of packing.

Top packing in tray vs. a collar filled with packing.—Hives C and D1 are alike, except for the top packing. In Hive C the tray does not extend beyond the inner wall of the hive. In Hive D1 the top packing was placed in a collar extending to the outer wall of the hive (no tray). In Hive C the inner temperature was 36.7° C., and in Hive D1 it was 39.9° C. above that of the outside air, a difference of 3.2° C. in favor of the packing which extends to the outer wall. The effect of using a tray extending to the outer wall is equally beneficial.

Fiber lining in double-walled hives.—A commercial insulating material used in refrigerator construction was substituted for sawdust in Hive D3. With the special lining the inner temperature was 41.5° C. above that of the room, as against 39.9° C. for sawdust packing, an advantage of only 1.6° C.

Wood vs. metal-covered wood for covers.—Very little can be determined from these tests as to this point. In Hives D1 and D2 were given two tests, showing a slight advantage (1.2° C.) for the all-wood cover.

Lining within the hive.—Hive E1 was lined with a commercial insulating material one-half inch in thickness. The tests indicate that the insulation of the wood and lining are not equal to that of the double-walled hives with sawdust packing, although it approaches the air-spaced hives in insulating value. In test E1 two pads of this material were placed on top of the hive, but none on the bottom.

Loss of heat through hive bottoms.—It is usually assumed by beekeepers that little or no heat is lost through the bottom of the hive. The tests made show that in all insulated hives this is the avenue through which heat is lost most rapidly. Even the single-walled hive (G) with a telescope cover lost slightly more heat through the bottom than through the top.

In Hive E2 one of the top pads of insulating material was removed and placed between the bottom board and the hive body, which would of course not be practicable in the apiary. This caused an increase in the inner temperature from 32.3° C. to 35.65° C. above the temperature of the outer air, a difference of 3.35° C., in spite of the decreased insulation on top.

Tests F1 and F2 were on an ordinary single-walled hive covered outside with 1½-inch flax-board insulation. When this was placed only on the sides and top, the inner temperature was 37.8° C. higher than the room temperature, but when the bottom board was removed from the hive and a slab of the insulating material was placed underneath the hive (a condition not practicable in the apiary), the temperature rose to 49.75° C. above that of the room, or an increase of 11.95° C.

To test this further, a special bottom was made to fit Hive B (test Hive H). A box was built of ⅜-inch material, using the regular ⅞-inch hive bottom as the top of the box and allowing 2 inches of sawdust between. When this was used, the temperature rose to 51.3° C. above that of the room, as against 42.45° C. without the special bottom, or a gain of 8.85° C.

COMPARATIVE VALUE OF VARIOUS INSULATING MATERIALS.

There has been considerable discussion among beekeepers regarding the comparative value of the more common materials which are used in insulating double-walled hives or in packing cases put about

the hives during winter. It is rather outside the scope of the present work to make tests of this kind, but as the information is important to the beekeeper, certain figures are given here. These are taken from the Smithsonian Physical Tables.[1]

In these figures the coefficient of conductivity is the quantity of heat in small calories which is transmitted per second through a plate 1 cm. thick per square centimeter of its surface when the difference of temperature between the two faces of the plate is 1° C. The coefficient of conductivity varies slightly with the temperature, but these slight variations need not be considered here. The smaller the coefficient of conductivity, the higher the insulating value of the material. For purposes of comparison, certain metals and other materials are also given.

Material.	Coefficient of conductivity.
Copper	1.000
Aluminum	.480
Beeswax	.0009
White pine	.00027
Snow (fresh)	.00026
Sawdust	.00012
Cork	.0007(?)
Corkboard (pure)	.000106
Pure wool	.000084
Cotton wool	.00010
Planer shavings (variable)	.00014
Balsa wood	.00012
Eel grass (in burlap)	.00011
Fibrofelt	.000113
Air (without radiation or convection)	.00006
Vacuum	.000002

It will be clear from these figures that in providing one of the common materials used for insulating beehives, the smaller the air spaces within the material, and the more numerous these spaces are, the better the material will be for insulation purposes. Thus sawdust or chaff is better than uncut straw. An air space would be ideal if all radiation and convection could be prevented, but as this is impossible, the use of the so-called dead-air spaces is not to be recommended. Exaggerated claims have been made for certain materials by beekeepers who have used them, but it will be clear from the foregoing figures that one is not apt to find any commercial insulating material which exceeds in insulating value the common materials such as sawdust. The practicability of various materials depends on factors other than insulating value; sawdust, for example, holds moisture, while clover chaff does not. The cost of the various materials and the ease of handling them will to a large degree determine their practical value.

[1] Fowle, Frederick E. Smithsonian physical tables, 7th rev. ed., Smithsonian Miscellaneous Collections, vol. 71, No. 1, 1920.

TESTS IN THE APIARY.

At the close of the tests previously recorded, all of the hives were used in the apiary of the Bureau of Entomology, and the results obtained have considerable bearing on the questions involved in this paper. Under ordinary winter conditions near Washington, most colonies of bees will live through the winter and come out in moderately good condition in the spring when housed in either single or double-walled hives. During the winter of 1917–18 almost all colonies in the experimental apiary were permitted to go into winter quarters with a considerable amount of honeydew as winter stores, as a test of the effects of inferior food on the wintering of bees. Certain colonies were given a small amount of sugar sirup after brood-rearing had ceased, which they placed below the other food reserve in their combs, and which they consequently used first, or during the period of cold weather. All such colonies came through the winter in excellent condition.

The remainder of the apiary with honeydew stores consisted of 60 colonies wintered in quadruple winter cases[2] and 8 colonies wintered in the hives which had been used in the tests previously recorded. Because of the quality of the food used by the bees which were not given sugar sirup, there was a heavy death rate among the bees with the following results: All the bees in the colonies in double-walled hives died, having shown the condition known as dysentery early in December. Of the colonies in quadruple winter cases, all the bees died in three, and these were all colonies that at the period of requeening in August had refused to accept the first queens given them and had consequently been queenless for too long a period during the month of August, when they should have been rearing bees for the winter period. It is impossible to measure the actual results of the use of poor food merely by the total loss of colonies, for many of the colonies which still lived suffered from dysentery and were appreciably weakened in numbers, but the death of all those in double-walled hives, as against a death of only 5 per cent in colonies in the quadruple cases, is significant.

A factor which was eliminated in the tests of insulating value, but which could not be eliminated in the apiary tests, is the comparative sizes of the entrances. In the quadruple winter cases all entrances were reduced to one small opening one-half inch in diameter during the coldest part of the winter, while in the double-walled hives it has been found impossible to have the entrances so small because of the danger that the entrances will be clogged by dead bees. It therefore appears that the insulation of an insufficiently insulated

[2] For a description of the quadruple cases used in the Bureau of Entomology apiary, see Farmers' Bulletin 1012, fig. 2.

hive is not used to the fullest extent because of this danger, and this serves to emphasize the desirability of abundant insulation. This subject has been discussed in Farmers' Bulletin 1012 of the Department of Agriculture, to which the reader is referred.

While in the experiments on the effects of poor food just described the double-walled hives proved insufficient, it may be argued that in apiary practice the beekeeper should provide his bees with honey of good quality, or with sugar sirup, and that if this had been done the colonies in double-walled hives would not have died. This is quite probable, and it is recommended in the publications of the Department of Agriculture that food be given serious consideration. Not all beekeepers, however, will take the necessary steps regarding the quality of food for winter, and it is quite clear that, while insulation does not take the place of good stores, abundant insulation does reduce the loss from poor food, and is therefore an important step in the preparation for winter.

CONCLUSIONS.

Many of the results obtained might have been foreseen solely from a physical examination of the hives, but it has seemed best to get accurate figures to substantiate the suppositions. The shape of the hive, and especially the various forms of bottoms, makes an accurate forecast of the various results more difficult.

Obviously from the temperature tables all the special hives tested are superior to a single-walled hive in insulating value.

The loss of heat is most rapid through the bottom of all the insulated hives tested, and the insulation on top and sides is never used to its full capacity as so much of the heat escapes below. This is quite contrary to the usual belief, or at least the practice of beekeepers, who, on the erroneous supposition that "heat rises," fail to insulate the bottoms. This serious defect should be remedied in all the commercial insulated hives.

It is clear from the results of these tests that the leaving of any portion of the hive without insulation renders the escape of heat at that point easy. Some beekeepers, in addition to leaving the bottoms of their hives unprotected, also leave the fronts, facing the south, unpacked on the theory that the warming of the hive by the sun will be of benefit. Such an arrangement to a large degree nullifies any insulation that may be applied, as it leaves a large area through which heat may readily escape.

There is relatively little heat lost through the tops of the insulated hives and only slightly more through the insulated sides in the regular commercial double-walled hives. This is due to the ease with which heat passes through the bottoms.

Air-spaced hives have less insulating value than those of the same dimensions in which the spaces are filled with insulating materials. The insulating value of all ordinary insulating materials depends on the air spaces confined in the material, and the insulating value is increased by increasing the number and decreasing the size of these spaces. In the so-called dead air spaces in hive construction there are doubtless convection currents within each cavity which tend to dissipate the heat.

It is better to use a tray extending to the outer wall of the top collar, or to fill the collar without a tray, instead of using a tray which covers merely the top of the inner hive.

If insulating material is used as a lining or cover it should be thick enough to give adequate insulation. In hive E1 the one-half-inch material does not equal in insulating value a double-walled hive provided with 1 inch of sawdust, but is nearly as good as an air-spaced hive.

The figures presented might be interpreted as showing the superiority of certain commercial insulated hives over others, but it should be clear from the figures presented that none of these hives as used by the beekeeper affords adequate insulation for a colony of bees at low temperatures. They do not compare favorably in insulating value with a well-insulated tenement hive holding four colonies, for example, for which figures are not presented. This inefficiency is chiefly due to the lack of bottom insulation, and if this were remedied, as could be done so easily, all of these hives would be measurably more effective.

Since sawdust or other insulating material costs so little, it would seem advisable to increase the thickness of the space for insulation of all these hives to perhaps 4 or even 6 inches if they are to be used in cold climates, allowing the beekeeper to fill this space with cheap insulating materials. Unless the bottoms are insulated there is no advantage in more insulation at tops or sides.

The hives used in these tests might be serviceable as protection for colonies of bees in the extreme southern parts of the country, or for use in connection with cellar wintering, but they are obviously inadequate for outdoor wintering in the North, and no such claim should be made for them.

Attention should again be called to the fact that in these tests there were no variations due to differences in entrances, as all entrances were closed during the tests.

TABLE I.—*Temperatures in tests of insulated hives.*

[All figures are of degrees centigrade.]

Hive.	Room temperature.	Bottom.			Side.			Top.			Air inside.	
		Outside.	Inside.	Difference.	Outside.	Inside.	Difference.	Outside.	Inside.	Difference.	2 inches from bottom.	2 inches from top.
A	19.8	12.7	29.15	16.45	6.6	29.35	22.75	2.25	35.5	33.25	29.2	32.45
B	19.8	16.8	37.2	20.4	5.4	42.9	37.5	4.35	44.05	39.7	38.9	42.45
C	19.85	14.3	31.65	17.35	5.8	35.75	29.95	3.5	39.25	35.75	34.05	36.7
D1	19.6	15.6	34.25	18.63	5.95	38.7	32.75	2.6	42.75	40.15	37	39.5
D2	17.85	15.8	35.1	19.3	6.25	39.65	33.4	1.75	43.9	42.15	37.55	41.1
D3	19.7	15.95	35.5	19.55	5.2	39.75	34.55	2.25	44.1	41.85	37.8	41.5
D4	22.2	13.75	30.4	16.65	6 9	30.9	24	2.9	37.65	34.75	31.5	34.8
E1	22.8	13.5	28.15	14.65	8.5	30.15	21.65	6.95	33.35	26.40	29.4	32.3
E2	23.6	8.3	35.35	27.05	8.7	33.45	24.75	9.6	35.6	26	34.5	35.65
F1	23.35	11.85	32	20.15	4.2	36.25	32.05	5.75	37.1	31.35	35.3	37.8
F2	20.85	12.05	47.05	35	6.2	49.1	42.9	7.15	50.25	43.1	47.1	49.75
G	18.5	10.6	22.75	12.15	7.5	19.9	12.4	5.2	21.35	16.15	21.1	22.1
H	18.65	7.25	50.8	43.55	5.5	50.45	44.95	4.25	53.3	49.05	49.25	51.3

NOTE.—Except for the column showing actual room temperature at the conclusion of each test, all figures in this table represent *difference in temperature* between the room temperature and that of the spot indicated. Thus for Hive A, the room temperature (19.8° C.) was 12.7° C. lower than that of the outside of the bottom, or the temperature of the outside of the bottom was actually 32.5° C. The plan here followed makes it unnecessary to make corrections for variations in room temperature in comparing the figures for the several hives in the different columns.

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